Science of the Total Environment 615 (2018) 1355–1363

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Impact of forest maintenance on water shortages: Hydrologic modeling and effects of climate change

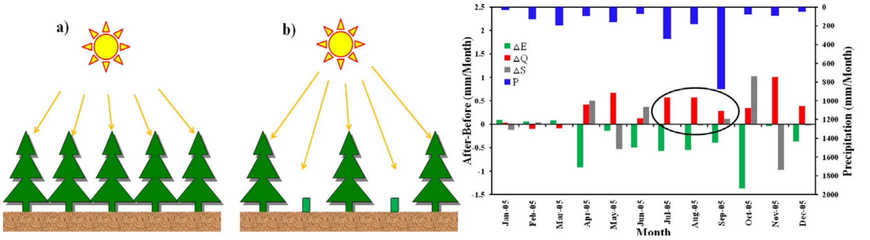
Pingping Luo [a,b,*], Meimei Zhou [a,b], Hongzhang Deng [a,b], Jiqiang Lyu [a,b], Wenqiang Cao [c], Kaoru Takara [c], Daniel Nover [d], S. Geoffrey Schladow [e]

[a] *Key Laboratory of Subsurface Hydrology and Ecological Effects in Arid Region, Ministry of Education, Chang'an University, Xi'an 710064, China*
[b] *School of Environmental Science and Engineering, Chang'an University, Xi'an 710064, China*
[c] *Disaster Prevention Research Institute (DPRI), Kyoto University, Uji, Kyoto 6110011, Japan*
[d] *School of Engineering, University of California – Merced, 5200 Lake R, Merced, CA 95343, USA*
[e] *Dept. Civil and Environmental Engineering, UC Davis, Ghausi Hall, One Shields Ave, Davis, CA 95616, USA*

HIGHLIGHTS

- We present a model to explore impact of forest management on hydrologic processes.
- Results indicate that surface flow and soil water increases after forest management.
- Climate change has little impact on near-future discharge, dramatic impact by 2100.
- Climate change leads to reduced soil moisture in the future period.
- Forest hydrology models show potential for informing environmental management.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 February 2017
Received in revised form 23 July 2017
Accepted 5 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Forest maintenance
Drought
Soil water
Surface flow
Climate change

ABSTRACT

The importance of water quantity for domestic and industrial water supply, agriculture, and the economy more broadly has led to the development of many water quantity assessment methods. In this study, surface flow and soil water in the forested upper reaches of the Yoshino River are compared using a distributed hydrological model with Forest Maintenance Module under two scenarios; before and after forest maintenance. We also examine the impact of forest maintenance on these variables during extreme droughts. Results show that surface flow and soil water increased after forest maintenance. In addition, projections of future water resources were estimated using a hydrological model and the output from a 20 km mesh Global Climate Model (GCM20). River discharge for the near-future (2015–2039) is similar to that of the present (1979–2003). Estimated river discharge for the future (2075–2099) was found to be substantially more extreme than in the current period, with 12 m^3/s higher peak discharge in August and 7 m^3/s lower in July compared to the discharges of the present period. Soil water for the future is estimated to be lower than for the present and near future in May. The methods discussed in this study can be applied in other regions and the results help elucidate the impact of forests and climate change on water resources.

1. Introduction

Water is both the foundation of human societies and a major source of vulnerability to extreme events such as droughts and floods. Water

---

[*] Corresponding author at: Key Laboratory of Subsurface Hydrology and Ecological Effects in Arid Region, Ministry of Education, Chang'an University, Xi'an, 710064, China.
E-mail address: lpp@chd.edu.cn (P. Luo).

https://doi.org/10.1016/j.scitotenv.2017.09.044
0048-9697/

shortages and droughts are increasing in frequency and intensity as climate change and population growth compound already strained water resource systems (Brekke, 2010). Global climate change is likely to lead to higher evapotranspiration and consequently enhance drought occurrence (Harriet Bigas et al., 2012) as population growth simultaneously increases water demand. Human activities have caused increasing concentrations of atmospheric CO_2 and other gases in the atmosphere which lead to increases in potential evapotranspiration and, as a consequence, surface heating (Trenberth et al., 2014). This may increase actual evapotranspiration which contributes to drought conditions. Both frequency and intensity of drought conditions in many countries appear to be increasing, e.g. Britain in 2012 (Bell et al., 2013), Serbia in 2000 (Gocic and Trajkovic, 2013), South China after 2003 (Zhang et al., 2013), United States in 2011–2012 (Grigg, 2014), European-wide in 2003 (Byzedi et al., 2014), Moscow region in 2010 (Lupo et al., 2014), etc. Droughts affect woody plant mortality (Twidwell et al., 2014), cave species (Shu et al., 2013), plant growth in general (Lipiec et al., 2013), and children's respiratory health (Smith et al., 2014), among many effects. Additionally, severe water shortages will be coincident with increasing water stress with important implications for human health (Oki and Kanae, 2006; Eliasson, 2015) and water pollutions problem (He et al., 2011). Droughts have adverse impacts on water quality with responses in water temperature, eutrophication, major ions and heavy metals (Zwolsman and van Bokhoven, 2007). Forest maintenance studies are essential to reduce drought stress and water shortages, particularly as droughts become increasingly serious and threatening to human societies and the environment.

The effect of forests on hydrology has been explored in numerous studies. Forests can store water during flood events, a function that can be lost when soils are fully saturated during extreme rainfall events (Scherrer et al., 2007). Forests have a significant impact on extreme flows by contolling flood routing (Eisenbies et al., 2007). Soil erosion increases under poor forest management (e.g. clear cutting or over-harvesting) (Grace, 2004). The impact of forest use and reforestation on soil hydraulic conductivity has been studied in the Western Ghats of India (Bonell et al., 2010). Many studies focus on future challenges and directions of forest hydrology. Forest gap models have been applied successfully to simulate tree species composition and have been improved to simulate patterns of aboveground biomass more realistically along drought gradients (Bugmann and Cramer, 1998). The impact of droughts on forest growth at different time scales has been investigated to understand forest response to climate change, and the increasing frequency of droughts (Pasho et al., 2011). Nakai and Kisanuki (2011) investigated tree cutting impact of two specific tree species in the Yoshino River basin. However, the impact of forest maintenance on Japanese river basins remains an important topic, particularly given the implications for water shortages in the context of climate change.

The warming of the climate system has led to changes in climate variables and caused increases of extreme climate conditions, e.g. storms and droughts. Previous researches have focused on drought hydrology and climate change impacts on droughts. The Standard Precipitation Index (SPI) is used for long-term drought forecasting (Belayneh et al., 2014; Raziei et al., 2013), multivariate approaches have been added to the SPI (Bazrafshan et al., 2014), and a Multivariate Standardized Drought Index has been coupled with the Standardized Precipitation Index (SPI) and the Standardized Soil Moisture Index (SSI) (Hao and AghaKouchak, 2013). Burke and Brown (2010) assessed regional drought events in the UK to predict future change due to increases in greenhouse gas concentrations. Recent research has also characterized uncertainty based on the choice of drought index and the internal variability of the Canadian Regional Climate Model driving data (PaiMazumder and Done, 2014). Other modeling studies investigated the combined uncertainties in GCM output, scenarios choice and downscaling method (Raje and Mujumdar, 2010). Stringer et al. (2009) assessed the impact of international and national policies in support of local adaptive strategies in southern Africa on the three interlinked drivers of climate change, desertification and drought. The impacts resulting from land-use and climate change on droughts have been analysed using physically-based models in the Netherlands (Hupsel, Gulp and Noor), Norway (Haugland) and Scotland (Monachyle) (Querner et al., 1997). However, little research has analysed droughts using hydrological models and high resolution GCM data in Japanese river basins.

The main objectives of this study are to analyse the change of surface flow and soil water under extreme droughts before and after forest maintenance, and to project future water resource conditions and soil water concentrations using a distributed hydrological model driven by 20 km mesh high resolution GCM data for Japan. Additionally, we discuss the role of forests and forest maintenance in ameliorating drought severity. Management recommendations are provided for future forest management with consideration to extreme droughts and future climate scenarios.

2. Study site and data collection

2.1. Description of study site

We focus on the upper reaches of the Yoshino River, Kochi Prefecture in the Shikoku Island of Japan. The upper basin of the Yoshino River (Fig. 1) is the upper stream from the Sameura Dam. The Sameura Dam is used for hydropower, flood control, domestic water supply, and irrigation. The Yoshino River is the second longest river on Shikoku Island, spreading over the island's four prefectures (Kamada et al., 1997). The river has a long history of flood control beginning in 1585 during the Edo period.

The basin area of the upper Yoshino River is about 389 km^2. The highest elevation is 1890 m, and the lowest elevation is 313 m. The annual rainfall in the mountainous area of this catchment is 2500 to 3000 mm, and most rainfall is concentrated from July to September (Jaranilla-Sanchez et al., 2012). Extreme historical discharge from the Sameura Dam is 0 m^3/s during the dry season (October to February) and 4000 m^3/s during the wet season (July to September) (KPPDWRPD, 2011). In recent decades, water shortages became serious in the Yoshino river basin (Nyunt et al., 2014). Most serious water shortage after the construction of Sameura Dam happened in 2008 (Luo et al., 2011). Water storage in the Sameura Dam approached zero on August 31, 2008. After the construction of Sameura Dam the water use capacity of this dam is close to zero which sometimes continues for 20 days. From the 1960s to the 1970s, deforested areas of the Yoshino River were reforested. Reforested areas in the Yoshino River basin matured during the 1980s and 1990s. Ten parameters have been used in the SWAT model for this drought study. The detail description of those ten parameters is presented in Table S1.

2.2. SWAT model inputs

2.2.1. Digital elevation model (DEM)

The digital elevation model (DEM) came from published data of the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT). The original DEM was transferred into point shape files using ArcGIS9.3 Japanese version. The original DEM is 50 m mesh resolution. Original 50 m mesh DEM data was scaled into raster files at 100 m mesh. The DEM (Fig. 1) is used to delineate the watershed boundary, river channel network, flow direction, flow accumulation and subbasins.

2.2.2. Soil type

Soil type data was downloaded from the land and classification survey at the website of Land and real property in Japan, Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT). Soil type data is 1:200,000 seamless. The original soil type data was converted into 100 m mesh raster file. The main classifications of soil type include